DECLARATION

I, William L. Androlia, state and verify that I am the attorney of record for Applicant, the attached paper is a substitute specification of Application Serial No. 09/856,005 filed on May 16, 2001, and no new matter has been added.

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SPECIFICATION

CDMA COMMUNICATION SYSTEM USING CODE SEQUENCE SET HAVING NO CROSS CORRELATION REGION

TECHNICAL FIELD

The present invention relates to a direct sequence spread spectrum (DS-SS) communication system, and more particularly to a code division multiple access (CDMA) communication system, capable of avoiding interference and disturbance caused by multiplex communications by employing an expanded binary spreading sequence set (ZCCZ sequence family) so that the correlation characteristics of the spreading sequences being used may have a zero correlation zone (ZCZ), and also enhancing the frequency utilization efficiency.

BACKGROUND ART

Spread spectrum communication is to send transmit-data data on a relatively narrow band spectrum by spreading the spectrum to a wide frequency band by modulating the spreading sequence by the transmission data, and it is an excellent communication system having many features including small transmit-power per unit frequency, relatively small interference to other communication, and satisfactory tolerance to environmental noise by mixing it in the transmission process, that is, general incoming noise and interference noise coming in from other mobile stations or interference stations than the desired station. However, since communications from multiple

stations have to share the same band and the same time, disturbance due to interference noise is dominant.

Fig. 13 is a block diagram showing a prior art that is a conventional and general configuration of a mobile communication system for spread spectrum communication through a wireless communication path, in which a transmitter TX modulates a spreading sequence by binary transmission data b to obtain base band transmission output s(t) as a transmit-symbol (a time limited signal conveying a sequence often modulated by data is here named by symbol, frame, or symbol frame). The sequence is generated by a spreading sequence generator 1. The output s(t) modulates the carrier of frequency f_0 generated by an oscillator 2. TX transmits the modulated output as a radio-band transmit-symbol to a receiver RX through a wireless communication path. As the spreading sequence, it is general to use pseudo-noise (PN) sequence of the same length (number of chips in sequence) as the spreading factor N. Since Gold code (a set of G sequences) having many code words (sequences) are well known, and used widely as PN sequences, the explanation is described below with G sequences.

The receiver RX applies the received symbol an amplifier 3 through an antenna (not shown here). Amplifier 3 amplifies it to a specific level, and mixes the amplified symbol and local carrier wave f_L (frequency and phase of f_L coinciding with f_0) supplied by a local oscillator 4, and produces a received base band symbol r(t) through a low pass filter 5. This is coherent demodulation.

This base band spread symbol and the same spreading sequence code (G sequence) as the code used in the transmitter TX generated from a spreading sequence generator 6 are put into a multiplier 7, the product output of multiplier 7 is integrated over the sequence (one symbol) period by an integrator 8, and a matched filter output is obtained. That is, multiplier 7 and integrator 8 makes matched filter (a correlator) for optimum demodulation. The output of integrator 8 is detected by a detector 9 at a final point of the symbol frame, by comparing with a threshold level for hard decision, to produce a binary data ^b. (In this specification, the hat and tilde to be shown on the top of a symbol are provided before the symbol.) A control signal produced by using this detected data is put into a control terminal of spreading sequence generator 6 through a synchronizing detector 10, and the generation timing of G sequence is controlled so as to be synchronized in phase with the received signal. In receiver RX shown in Fig. 12, the multiplication function by the local oscillator 4 and spreading sequence generator 6 is often replaced, but the entire demodulation function is exactly the same.

Supposing examples of two G sequences to be $g_0(i)$ and $g_1(i)$, they are shown in Fig. 14 (a), where i is a time variable showing the i-th chip position. Since G sequence is a binary sequence, the symbol frame waveform is, supposing the sequence length L, a binary L chip impulse sequence (actually, as the chip waveform, instead of impulse without energy, a square wave or a sampling function waveform is used; in the diagram, however,

each chips is illustrated by an impulse). As the binary value, usually ±1(V) is used, and +1 and -1 are expressed as + and - herein.

The periodic auto-correlation function (ACF) and aperiodic auto-correlation function (AACF) of $g_0(i)$ are shown in Fig. 14 (b), and the cross correlation function (CCF) and aperiodic cross correlation function (ACCF) between $g_0(i)$ and $g_1(i)$ are shown in Fig. 14 (c). On the axis of abscissas in the diagram, τ is a shift variable taking an integer.

Supposing the binary transmission data of a desired station u_0 whose data should be detected chosen out of all user stations to be b_{0n} (n = ..., -1, 0, 1, 2, ...), its transmission wave (base band waveform) is $b_{0n}g_0(i)$, but multiple delayed waves (including preceding waves) are generated by the multi-path effect in the transmission process. Among them, usually, the received wave (synchronously received symbol frame) synchronized with the strongest wave in power coming from the desired station is received, and then demodulated. In this demodulation process, the delayed waves become auto-interference waves. When the preceding and present frames carry information of the same polarity (with respect to the preceding transmission data b_{0-1} and present transmit-data b_{00}), disturbance corresponding to the auto-correlation function (ACF) takes place. On the other hand, if different in polarity ($b_{0-1} \cdot b_{00} = -1$), disturbance corresponding to two aperiodic auto-correlation functions (AACF) (corresponding to odd auto-correlation) takes place.

Received waves [composed of $b_1g_1(i)$, its delayed waves, and preceding waves] corresponding to a transmitted wave from an interference station u_1, one of the stations other them the desired one, included in the received symbol synchronized with that coming from the desired station are co-channel interference. In this case, when the preceding symbol ($b_{1-1}g_1(i)$) and present symbol ($b_{10}g_1(i)$) are of the same polarity ($b_{1-1}b_{10}= 1$), it is called even cross correlation, and interface corresponding to cross-correlation function (CCF) takes place. In the case of different polarities ($b_{1-1}b_{10} = -1$), it is called odd-cross correlation, and interference corresponding to two aperiodic cross-correlation functions (ACCF) take place.

The shift time τ (axis of abscissas) of respective correlation functions correspond to the time difference between the synchronously received symbol and interference symbol. From the characteristics in Fig. 13 (b) and (c), it is known that the absolute correlation value is of considerably large. Actually, supposing the number of system users K and the number of multi-paths including desired wave (2M+1), if limited only to the case of even correlation, the number of interference symbols generating auto-correlation is 2M and the number of interference symbols generating cross correlation is (K-1)(2M+1). If limited to the case of odd correlation only, both the numbers are doubled.

Therefore, summing up the values in Fig. 13 (b), (c) corresponding to the polarity of respective transmit-data, the whole interference due to multiple waves is obtained. When the

interference amplitude distribution is given, the rate of exceeding the threshold (the correlation value corresponding to the synchronously received symbol addressed to the desired station coming into the receiver) increases as K and M increase, thereby increasing the bit error rate. In CDMA communication systems, generally, the service area is divided into plural cells, and a base station in each cell communicates with the users belonging to the cell via up- and down-links, but the up- (down-) links of all the cells use the same frequency band. Therefore, the base station receiver receives waves transmitted by users in adjacent cells as interference noise, being subjected to the disturbance.

To avoid interference disturbance, a means of decreasing the number of users K per cell or a technique of "convolutional coding" in addition to spreading sequence are employed. If the convolutional coding rate is $r_c = 1/3$, the symbol length increases to substantially (L/r_c) chips. The decrease in K or in r_c directly results in reducing the frequency utilization efficiency of the system. Therefore, the problem is that the number of chips of present systems required to send one bit [the measure of (chips/bit) will be mentioned later] is extremely larger than 1.

It is hence an object of the invention to present technology capable of realizing a system free from interference component such as auto-interference, co-channel interference or inter-cell interference, or a system capable of decreasing the interference component remarkably, by designing particular

sequence families and using them.

DISCLOSURE OF THE INVENTION

To solve the problems, according to the invention as set forth in the first aspect, a transmitter comprises means for preparing binary ZCCZ spreading sequences belonging to a family of sequence groups in which no periodic cross correlation function between an arbitrary pair of the spreading sequences exists for a correlation function region near 0 shift, as mutually different spreading sequences for identifying users, means for producing an expanded symbol which is made by adding guard sequences to both sides of the ZCCZ sequence that is the central frame, and means for producing a transmission base band symbol by multiplying the expanded symbol by a transmission information, and a receiver comprises means for receiving the received base band symbol corresponding to the transmitted base band symbol, and means for demodulating the received frame in correlation with the ZCCZ spreading sequence used by the transmitter of a desired station or a local sequence for demodulation as reference sequence, and hard decision making of the demodulated output.

The invention as set forth in the second aspect relates to the first aspect, in which each user transmitter belonging to a communication system comprises means for transmitting an isolated pilot frame, and a base station receiver comprises means for producing respective cross correlation function responses of the isolated pilot frames incoming from the user transmitters with an arbitrary spreading sequence or an auto-orthogonal

sequence, and means for producing a demodulated output by analyzing the received base band frame with the cross correlation function response set.

The invention as set forth in the third aspect comprises, in order to produce the ZCCZ spreading sequence used in the first aspect, means for preparing one sequence of sequence length N_1 belonging to a ZCZ sequence family of which periodic auto-correlation function has no auto-correlation region at both sides of the 0 shift, and of which periodic cross-correlation function between an arbitrary pair of sequences has no correlation region at both sides of the 0 shift, including the 0 shift, and for preparing a block sequence d with sequence length N_2 that is prime to N_1, which belongs a semi-orthogonal sequence family of which Hamming distance between an arbitrary pair of the sequences takes a relatively large value, and producing a repetitive ZCZ sequence and a repetitive block sequence by repeating both sequences so as to take a product sequence length N that is N_1 times N_2, and producing in advance a product sequence with sequence length N by multiplying both the repetitive sequences on the respective corresponding chip positions, in which the product sequence is used as the ZCCZ spreading sequence.

The invention as set forth in the fourth aspect relates to the third aspect, in which a product sequence S_{kp}^j is assigned to a system in a method of making the block sequence d hierarchical with a sub-block matrix H_p^* ($p = 1, 2, \ldots, P$), producing a family of product sequence S_{kp}^j made of the j-th ($j = 1, 2, \ldots, J$) block sequence d_{pj} belonging to H_p^* and the k-th ($k = 1, 2, \ldots, K$)

ZCZ sequence C_k belonging to the ZCZ sequence family, and providing the stratified family elements k, p, and j with the system elements of cell number, user number, and transmission information level in an arbitrary order.

The invention as set forth in the fifth aspect relates to the fourth aspect, in which product sequence S_{kp}^j is assigned to the system in a method of providing a combined family composed of one to three elements of stratified family elements k, p, j with one system element, and a combined family composed of the remaining elements with other system elements.

The invention as set forth in a sixth aspect relates to the fourth or fifth aspect, in which the sequence corresponding to the family element assigned to the cell number of system elements is used as scramble code for transmission and descramble code for reception.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 (a) is a diagram showing received symbol frame sequences, (b) is a diagram showing a composition of an expanded frame, and (c) is a diagram showing a composition of expanded frame sequences.

Fig. 2 (a) is a diagram showing a transmitter base band circuit in an embodiment of the invention, and (b) is a diagram showing a receiver base band circuit.

Fig. 3 (a) is a diagram showing a correlation characteristic having a zero correlation region, relating to cross correlation characteristic ($k\neq k'$) between different

partial sets, (b) is a diagram showing a correlation characteristic having a zero correlation region, relating to cross correlation characteristic ($j \neq j'$) between same partial sets, and (c) is a diagram showing a correlation characteristic having a zero correlation region, relating to auto-correlation characteristic.

Fig. 4 (a) is a diagram showing an example of composition of 4-ZCZ sequence C, and (b) is a diagram showing an example of composition of its periodic correlation R.

Fig. 5 (a) is a diagram showing an orthogonal cord H, and (b) is a diagram showing a block code d.

Fig. 6 is a diagram showing an example of composition of set S of 4-ZCZ sequence.

Fig. 7 is a diagram showing periodic correlation characteristics of a set S in Fig. 6.

Fig. 8 (a) is a diagram showing 2-ZCZ sequence C, and (b) is a diagram showing its periodic correlation.

Fig. 9 is a diagram showing an example composition of a diagonal matrix element set of binary block code.

Fig. 10 is a diagram sowing a hierarchical structure of a composite set of 2-ZCCZ sequences.

Fig.11 is a block diagram showing the method of constructing a composite set of ZCCZ sequences.

Fig. 12 (a) is a diagram showing a transmitter base band circuit having a function of transmitting an isolated pilot and Fig. 12 (b) is a diagram showing a receiver base band circuit having a data symbol analyzing function with pilot responses

in a second embodiment of the invention.

Fig. 13 is a prior art showing a diagram of a transmitter and a receiver of a direct sequence spread spectrum communication system.

Fig. 14 is a prior art, (a) is a diagram showing Gold sequences used for spreading sequences, (b) is a diagram showing periodic and aperiodic auto-correlation functions, and (c) is a diagram showing periodic and aperiodic cross-correlation functions.

BEST MODE FOR CARRYING OUT THE INVENTION

«ZCZ sequence family characteristic»

In order to avoid interference including effects of delay waves, it is preferred to design a set of spreading codes in which the auto-correlation function (ACF) is an ideal pulse and the cross correlation function (CCF) has an ideal zero value, but this is impossible. It is, however, possible to compose a set of sequences (ZCZ sequence family) having a zero correlation zone (ZCZ) in part of a shift region of ACF/CCF.

The ZCZ sequence is a sequence in which the correlation value takes 0 in a limited shift range $\tau = -\Delta$ to Δ ($\Delta < N/2$) centered on $\tau = 0$ (excluding $\tau = 0$ as for ACF) in the whole shift range $\tau = -N/2$ to $N/2$ centered on $\tau = 0$ when using ZCZ sequence family with sequence length N (even number). Such ZCZ family can be made from a complementary sequence pair, and can be shown by 2Δ-ZCZ.

Denoting a complementary sequence pair with sequence

length (N/4) by [A, B], and the respective aperiodic auto-correlations with shift variable τ by $\hat{R}$ [A,A, τ], $\hat{R}$[B,B, τ], they are defined as follows.

$$\left.\begin{array}{ll}\hat{R}[A,A,\tau]+\hat{R}[B,B,\tau]=N/2 & (\tau=0)\\ \qquad\qquad =0 & (\tau\neq 0)\end{array}\right\} \quad \cdots (1)$$

Preparing a similar complementary sequence pair [A', B'], a pair of other sequences with sequence length N is obtained by connecting them in cascade.

$$P=(A,B,A,\overline{B}) \qquad (\overline{B}=-B)$$
$$Q=(A',B',A',\overline{B}') \qquad (\overline{B}'=-B')$$

where -B, -B' are sequences inverted in polarity of sequences B, B'.

The periodic auto-correlation and periodic cross correlation are given by the following equations.

$$\left.\begin{array}{ll}R[P,P,\tau]=R[Q,Q\tau]=N & (\tau=0)\\ \qquad\qquad =0 & (1\leq|\tau|\leq\Delta)\end{array}\right\} \quad \cdots (2)$$

$$\left.\begin{array}{ll}R[P,Q,\tau]=0 & (|\tau|\leq\Delta)\\ \Delta=N/4 & \end{array}\right\} \quad \cdots (3)$$

In the above example, of the method of producing a ZCZ sequence, a case that the family size is M = 2 is shown, but a larger size family can be produced by the same technique. It is, however, known that the value Δ is decreases according to the following equation. (The detail is given in Collected Paper 1027 of Kyushu Branch General Meeting of the Institute of Electronics,

Information and Communication Engineers, 1998).

$$M = \frac{N}{2\Delta} \quad \cdots (4)$$

In conjunction with assigning respective sequences of ZCZ sequence family to M users, such a case is considered that the sum of the delay spread width τ_m^* of delayed waves user signal arriving time difference τ_a of user signals arriving at the receiver may be limited to less than Δ chips, as given by the following equation.

$$\tau_v = \tau_m^* + \tau_a \leq \Delta T_C \quad \cdots (5)$$

where T_C is the chip period, and τ_v is the time variation width. In this case, intra-cell interference disturbance can be avoided. However, suppression of inter-cell interference by using the ZCZ sequences is difficult because of the limited number of available sequences. Employing the ZCZ sequences only, on the other hand, the degree of design freedom is less than required, and it is difficult to perform practical design.

The invention, in order to avoid inter-cell interface, enhance the degree of freedom, and improve the frequency utilization efficiency, discloses a structural method of zero cross correlation zone (ZCCZ) having a structure of stratified sequence family and capable of realizing a large family size, and presents CDMA systems employing this sequence family.

«Framing technique»

It is only when the interference component contained in

the received frame for demodulation is composed of periodically repeated (cyclicly shifted) ZCZ sequences that a system using ZCZ sequences (also ZCCZ sequences to be mentioned below) can be processed without suffering interference.

Fig. 1 (a) shows an example of composition of received frame sequences in which two users transmit their signals and a base station receiver receives them. The received input is composed of a desired wave $v_s(t)$ of sequence P and an interference wave $v_x(t)$ of sequence Q. The polarity of each wave coming in is modulated independently by binary information as it is shown by P, -P, and Q, -Q. The frame positions of P and Q are generally different due to multi-path effect of the propagation process, and in the illustrated example, Q is delayed by τ_{PQ} as compared with P. (Herein, τ_{PQ} corresponds to τ_v in equation (5).)

When demodulating this received input, by the known synchronizing technology, a time width F_S equal to the period T of P (Q) is set for the synchronously received frame. F_S has the time position and time width coinciding with the received frame coming from a desired station. Generally, this synchronously received frame contains two interference wave sequences (combination of four types of Q and -Q). If the interference wave is composed of sequences of different polarities such as Q and -Q, a case of odd correlation takes place, and then the above periodic correlation equation can not be applied. That is to say, the ZCZ correlation characteristics which are consistent with only even correlation (when composed of combination of same polarity such as Q and Q) cannot be utilized.

To solve this problem, the system is designed so that the time difference τ_{PQ} between the received frame positions may be limited under a threshold, and an expanded frame format to be mentioned below is used. With a down-link channel of CDMA systems for mobile communication, by transmitting a timing control signal from the base station to a mobile station, the absolute value of τ_{PQ} can be limited less than a specified value. This is called a quasi-synchronous condition.

As shown in Fig. 1 (b), by copying the heading portion (ℓT_C, T_c: chip period) and tail portion (ℓT_C) of the spreading sequence P, and disposing them as in the rear and front slots outside the sequence P as P'_T and P'_H shown in the drawing, respectively, an expanded frame P_E with chip length $(N+2\ell)$ is formed. That is, the spreading sequence P with N chips is converted into a spreading sequence P_E with $(N+2\ell)$ chips. The frame period T_E of P_E is given as follows.

$$\left.\begin{array}{l} T_E = (1+\alpha)T \\ \alpha = 2\ell/N \end{array}\right\} \quad \cdots (6)$$

where α is the frame expansion rate. All the transmission frames are composed in this manner.

Fig. 1 (c) is a diagram showing a composition of expanded symbol frame sequences, in which the receiver takes out the synchronously received frame F_S, attempting to detect the basic sequence P in an expanded sequence P_E. A part of another expanded sequence Q_E included in F_S at this time is a cyclically shifted sequence Q_τ of the basic sequence Q. That is, it is the

interference of even correlation (periodic correlation). When this shift time is less than Δ, Q_E does not interfere the detecting operation of P, owing to the correlation characteristics of the ZCZ sequence. Thus, the guard sequence of ℓ chips added in the expanded frame has such a protecting function that the boundary of Q_E and $-Q_E$ may not be contained in F_S.

By using the expanded frames and quasi-synchronizing technology for limiting τ_{PQ}, the system using ZCZ sequence can operate without being subjected to interference. This system is effective when applied not only in up-link (asynchronous) transmission, but also in down-link (synchronous) transmission having the multi-path effect. In down-link, each user receives the respective main signals in a synchronous condition, but receives the delayed waves generated by each of them in an asynchronous condition such that the received wave position may be shifted.

«Transmitter base band circuit function»

Fig. 2 is block diagrams of a CDMA transmitter and a receiver in an embodiment of the invention. Fig. 2 (a) shows a transmitter circuit of the p-th user among P users belonging to the k-th cell among K cells composing this CDMA system. A data block denoted by $[b_{kpn'}]_n$ ($n'=1,2,\ldots,I$) named as the n-th data block consisting of I bits data where $b_{kpn'}$ is the n'-th binary transmit-data that the p-th user in the k-th cell should transmit to a base-station receiver.

Now, when data block $[b_{kpn'}]_n$ is applied to a multi-ary

converter Mary-C, it generates $J=2^{I-1}$ multilevel element outputs denoted by $[e_j(n)]$ $(j=1,1,\ldots,J)$, where one of the outputs $[e_j(n)]$ $(j\in 1,1,\ldots,J)$ takes a binary value $b_{kp}^{j}(\in \pm 1)$ and the other (J-1) outputs $e_{j'}(n)$ $(j' \neq j)$ take a value of zero. This is a multi-ary modulation method. Thus Mary-C performs multi-ary conversion from I bits data to J element signals. These outputs $[e_j(n)]$ are applied to a spreading circuit SC. As-MEM and TS-MEM are sequence memories and the former stores all the sequences to be used in this system, and the latter stores a set of the sequences $\mathbf{S}_{kp}^{j}(j=1,2,\ldots,J)$ which have been allocated temporarily to this user for communications with a base-station of the k-th cell. This set has been supplied from sequence memory As-MEM according to a control signal coming from said base-station. Thus the system can provide efficient services to potential users much larger than the number of total sequences prepared in the system. Therefore, a spreading circuit SC can prepare in advance J pieces of spreading sequences S_{kp}^{j} $(j = 1, 2, \ldots, J)$ and the respective polarity inverted sequences $\overline{S_{kp}^{j}}$, and generates an output $b_{kp}^{j}(\in \pm 1)$ $S_{kp}^{j}(n)$ that results in mapping I bit data block $[b_{kpn'}]_n$ to one of $2J$ $(= 2^I)$ sequences. $b_{kp}^{j}S_{kp}^{j}(n)$ is applied to a frame expansion circuit FE. FE generates an expanded frame $[b_{kp}^{j}S_{kp}^{j}]^E$ by adding a header and a tail to sequence $[b_{kp}^{j}S_{kp}^{j}]$ as explained in Fig. 1. Output $[b_{kp}^{j}S_{kp}^{j}]^E$ can be expressed as the n-th base band transmit symbol $\mathbf{s}_{kp}(n)$.

Base-band transmit symbol $\mathbf{s}_{kp}(n)$ and a carrier wave $c(t)$ are applied to a modulator MOD1 to generate an output $\mathbf{s}_{kp}^{f}(t-nT_E)$ as the n-th radio-band transmit symbol at the n-th symbol slot,

where T_E is an expanded symbol frame period.

Fig. 2 (b) shows a circuit of a base-station receiver, in which the base station of the k-th cell receives a received radio-band symbol $\mathbf{r}^f(t-nT_E)$ frame as an input symbol in which the symbol components {can be shown as $r_{kp}{}^t(t-nT_E)$} having been transmitted by all of users in this system are multiplexed. This circuit has a function of detecting data of a data-block which have been transmitted by the p-th user station of the k-th cell, which is generally called a desired user station whose data should be detected among all the users in the system.

A modulator MOD2 demodulates said radio-band symbol $r^f(t-nT_E)$ with a local carrier wave c(t) to produce a base-band received symbol at the n-th symbol slot, denoted by $\mathbf{r}(n)$. r(n) is applied to an and-gate A to extract the core-part of r(n) as a base-band received core-symbol $\mathbf{r}^*(n)$ with a timing pulse e_{sf}. A modulator MOD3 and an integrator INT composes a matched filter with a matting sequence $S_{kp}{}^j$, where each modulator output is integrated over a core-symbol frame period T by an integrator INT. With an input of core-symbol $r^*(n)$, respective matched filters produce correlation outputs denoted by $[\tilde{e}_j]$ (j=1, 1, ..., J), each is called the j-th soft output.

The j-th soft output $\tilde{e}_j$ is the 0-shift correlation between $r^*(n)$ and $S_{kp}{}^j$, and if $r^*(n) = b_{kp}{}^j S_{kp}{}^j$, then the soft output takes a normalized value, $\tilde{e}_j = b_{kp}{}^j (\in \pm 1)$. (This normalization is always adjusted by received pilot signals with conventional techniques.) However, respective soft outputs $[\tilde{e}_j]$ include not only the signal component $b_{kp}{}^j$, but also white noise and

interference components due to the other input symbol components $r_{kp}{}^{f}(t-nT_E)$ $(k' \neq k,\ p' \neq p)$. For this reason, a hard decision circuit DEC compares J pieces of the outputs, on the distances between the j-th soft output $\tilde{e}_j$ and the normalized value 1 or -1, respectively for j=1,2,...J. When the j'-th value $\tilde{e}_j$ is closest to 1 or -1 so as to satisfy the following equation,

$$\left.\begin{array}{l} j' = ary.\min(\tilde{e}_j,-1,\ \tilde{e}_j,+1) \\ (j = 1,2,\ldots,J) \end{array}\right\} \qquad (7)$$

DEC makes a decision on that the transmitter has transmitted $b_{kp}{}^{j'}S_{kp}{}^{j'}$ corresponding to the polarity of $\tilde{e}_{kp}^{j'}$, and thereby produce an output $\hat{e}_{kp}^{j'}(\in 1,-1)$ and the other outputs $\hat{e}_{kp}^{j} = 0\ \ (j \neq j')$ as detected values of the multilevel element signals. These detected outputs $[\hat{e}_j]$ are applied to a multi-binary level converter Bary-C, I bits of detected data block $[b_{kpn'}]$ $(n'=1,2,\ldots,I)$ are produced.

Thus, a multiary transmission system for the p-th user in the k-th cell is realized. The invention is to provide a system uses ZCCZ sequence family denoted by $S_{kp}{}^{j}$ so as to avoid the disturbance caused by many interference components contained in $r^{*}(n)$ coming from the other (KP-1) users.

[Production method of ZCCZ sequence family]

First, a set S is defined. The set S consists of K pieces of partial sets S_k $(1 \le k \le K)$, and each partial set S_k is a set composed of M pieces of element sequence S_k^j $(1 \le j \le M)$ with length N. The

periodic cross correlation characteristics of arbitrary element sequences S_k^j, $S_{k'}^{j'}$ which belong to mutually different partial sets S_k and S_k' ($k' \neq k$) are the same as shown in Fig. 3 (a). The periodic cross correlation characteristics of arbitrary sequences S_k^j, $S_k^{j'}$ which belong to the same partial sets S_k are the same as shown in Fig. 3 (b). (In Fig. 3, the correlation for $|\tau|>\Delta$ is shown as a constant value, it means generally a value not being 0.) The periodic auto-correlation characteristics of these element sequences have such features as shown in Fig. 3 (c). Composing method of the sequence sets satisfying these conditions is explained.

Let a and u be positive integers, and sequences which have a sequence length $N_1 = a2^{n^*}$, the number of partial sets $K = 2^u$, and zero correlation zone (ZCZ) $2\Delta = N_1/K = a2^{n^*-u}$ are denoted by C_k ($1 \leq k \leq K$). Hence, consider a set C consisting of K pieces of 2Δ-ZCZ sequence.

$$C = \{C_1, \ldots, C_k, \ldots, C_K\} \quad \cdots (8)$$

where C_k ($1 \leq k \leq K$) is the k-th element sequence of set C. Consider another set d which consists of M pieces of sequence with sequence length N_2 and has the maximum Hamming distance H with set C.

$$d = \{d_1, \ldots, d_j, \ldots d_{j'}, \ldots d_M\} \quad \cdots (9)$$

where d_j, $d_{j'}$ ($1 \leq j, j' \leq M$) are element sequences of d. The greatest common divisor of N_1 and N_2 is g. c. d (N_1, N_2) = 1, in other words, they are mutually prime. In this set d, the polarity inverted sequence of an element sequence is not included. The

0-shift cross correlation between a pair of the element sequences satisfies the following equation.

$$L - |R[d_j, d_{j'}, 0]| - N_2 - 2H \qquad \cdots (10)$$

where R $[d_j, d_{j'}, \tau]$ expresses the τ shift periodic cross correlation value between sequences d_j and $d_{j'}$.

Each partial set S_k ($1 \leq k \leq K$) of a set $S = \{S_1, \ldots, S_k, \ldots, \ldots, S_K\}$ is represented as a combination of C_k in equation (8) and block code $d = \{d_1, d_j, d_M\}$ in equation (9) as follows.

$$S_k - (S_k^1, S_k^2, \ldots, S_k^j, \ldots, S_k^M) \qquad \cdots (11)$$

$$S_k^j - C_k o d_j \qquad \cdots (12)$$

where $C_k o d_j$ is a sequence composed of the product of mutually prime sequences. That is, $C_k o d_j$ is a symbol letter which means producing a sequence $[c_k N_2]$ with sequence length $N = N_1 N_2$ by repeating C_k N_2 times, and a sequence $[d_j \bullet N_1]$ with sequence length N by repeating d_j N_1 times, and then producing a sequence S_k^j with sequence length N by adding the i-th (i = 1, 2, ..., N) chip values of both sequences (in modulo 2). This addition corresponds to the product operation when using binary values (+, -), and S_k^j is called the product sequence of C_k and d_j. This is also called ZCCZ (an expanded set of binary spreading sequences).

This composing method is explained with the following example. In Fig. 4, a 4-ZCZ sequence with $N_1 = 2^n = 8$ ($n^*=3$) is represented as

$$C = \{C_1, C_2\}$$

$$C_1 = (+ \; + \; + \; - \; + \; + \; - \; +), C_2 = (- \; + \; - \; - \; - \; + \; + \; +).$$

In Fig. 5 (a), excluding the first chip of an Hadamard code with sequence length 4, a block code d (partial Hadamard code) with M = 4 pieces and sequence length $N_2 = 3$ shown in Fig. 5 (b) is represented as

$$d = \{d_1, d_2 d_3, d_4\}, d_1 = (+ \; + \; +), d_2 = (- \; + \; -), d_3 = (+ \; - \; -), d_4 = (- \; - \; +).$$

In this example, N_1 and N_2 are mutually prime, and hence gcd $(N_1, N_2) = 1$.

Using C and d shown in Fig. 4, from equations (11) and (12), the following two partial sets composed of sequence groups with sequence length $N = N_1 N_2 = 8 \times 3 = 24$ can be derived.

$$\begin{aligned} S &= \{S_1, S_2\} \\ S_1 &= \{S_1^1, S_1^2, S_1^3, S_1^4\} \\ &= \{C_1 o d_1,\ C_1 o d_2,\ C_1 o d_3,\ C_1 o d_4\} \\ &= \{a, c, e, g\} \end{aligned}$$

$$\begin{aligned} S_2 &= \{S_2^1, S_2^2, S_2^3, S_2^4\} \\ &= \{C_2 o d_1, C_2 o d_2, C_2 o d_3, C_2 o d_4\} \\ &= \{b, d, f, h\} \end{aligned}$$

Examples of these sequences are shown in Fig. 4 to Fig. 6. Fig. 4 (a) shows a ZCZ sequence set C, and Fig. 4 (b) is its periodic correlation characteristics. Fig. 5 shows an Hadamard code H and a block code d derived from H, Fig. 6 shows a ZCCZ sequence set S produced from the sequences in Fig. 4 and Fig. 5. The correlation characteristics on set S in Fig. 6 is

shown in Fig. 7. The result satisfies Eqs. (2) and (3), and the characteristics in Fig. 3.

As another example of sequence sets C, 2-ZCZ sequences with sequence length $N_1 = 8$ are shown in Fig. 8. Based on an Hadamard matrix with sequence length 16, a block code with Hamming distance $h = 6$ can be produced. That is, using the following Hadamard matrix with sequence length $N_H = 16$,

$$H_{00} = \begin{pmatrix} + & + & + & + & + & + & + & + & + & + & + & + & + & + & + & + \\ + & - & + & - & + & - & + & - & + & - & + & - & + & - & + & - \\ + & + & - & - & + & + & - & - & + & + & - & - & + & + & - & - \\ + & - & - & + & + & - & - & + & + & - & - & + & + & - & - & + \\ + & + & + & + & - & - & - & - & + & + & + & + & - & - & - & - \\ + & - & + & - & - & + & - & + & + & - & + & - & - & + & - & + \\ + & + & - & - & - & - & + & + & + & + & - & - & - & - & + & + \\ + & - & - & + & - & + & + & - & + & - & - & + & - & + & + & - \\ + & + & + & + & + & + & + & + & - & - & - & - & - & - & - & - \\ + & - & + & - & + & - & + & - & - & + & - & + & - & + & - & + \\ + & + & - & - & + & + & - & - & - & - & + & + & - & - & + & + \\ + & - & - & + & + & - & - & + & - & + & + & - & - & + & + & - \\ + & + & + & + & - & - & - & - & - & - & - & - & + & + & + & + \\ + & - & + & - & - & + & - & + & - & + & - & + & + & - & + & - \\ + & + & - & - & - & - & + & + & - & - & + & + & + & + & - & - \\ + & - & - & + & - & + & + & - & - & + & + & - & + & - & - & + \end{pmatrix} \quad (13)$$

8 orthogonal matrix groups are produced, $H_1 = H_{00}[S_1]$, $H_2 = H_{00}[S_2]$,

$H_3 = H_{00}[S_3]$, ..., $H_8 = H_{00}[S_8]$. These matrices $[S_1]$, $[S_2]$, ..., $[S_8]$ are of made by using sequences s_1, s_2, ..., s_8 shown in Fig. 9 as diagonal elements, respectively, and an example of matrix $[S_2]$ is shown below as an example.

$$[S_2] = \begin{pmatrix} + &&&&&&&&&&&&&&& \\ & + &&&&&&&&&&&&&& \\ && + &&&&&&&&&&&&& \\ &&& - &&&&&&&&&&&& \\ &&&& + &&&&&&&&&&& \\ &&&&& + &&&&& 0 &&&&& \\ &&&&&& + &&&&&&&&& \\ &&&&&&& - &&&&&&&& \\ &&&&&&&& + &&&&&&& \\ &&&&&&&&& + &&&&&& \\ && 0 &&&&&&&& - &&&&& \\ &&&&&&&&&&& + &&&& \\ &&&&&&&&&&&& - &&& \\ &&&&&&&&&&&&& - && \\ &&&&&&&&&&&&&& + & \\ &&&&&&&&&&&&&&& - \end{pmatrix} \quad (14)$$

where sequence s_p ($p = 1, 2, \ldots, 8$) is a sequence belonging to a sequence family having a relatively large Hamming distance between the members.

Based on these matrices H_p ($p = 1, 2, \ldots, 8$), in order to produce sequences with length N_2 mutually prime to N_1, suppose to use a 16 × 15 matrix H_p^* which is made by excluding the first

row of matrix H_p. In H_p^*, the j-th sequence (code word) is denoted by block code d_{pj}.

Thus utilizing the same manner as that in Eq. (12), ZCCZ sequence S_{kp}^j is given by the following equation.

$$S_{kp}^j = C_k \odot d_{pj} \quad \cdots (15)$$

This ZCCZ sequence family has a three-layer structure as shown in Fig. 10, corresponding to the family element subscripts k, p, and j. That is, this example sequence family set is composed of:

First layer	S_k	$(k = 1, 2, \ldots, K)$	K sub-families
Second layer	H_p^*	$(p = 1, 2, \ldots, P)$	P mini-families
Third layer	S_{kp}^j	$(j = 1, 2, \ldots, J)$	J sequences

where K corresponds to the number of ZCZ sequences, P to the number of Hadamard matrices, and J to the degree of Hadamard matrix. The correlation characteristics between these sequences are:

- between sub-families

$$R[S_{kp}^j, S_{k'p'}^{j'}, \tau] = 0 \qquad [k \neq k', |\tau| \leq \Delta] \quad \cdots (16)$$

- between mini-families (within a sub-family)

$$\left.\begin{aligned} R[S_{kp}^j, S_{kp'}^{j'}, \tau] &= LN_1 & [p \neq p', \tau = 0] \\ &= 0 & [p \neq p', 1 \leq |\tau| \leq \Delta] \end{aligned}\right\} \quad \cdots (17)$$

- between sequences (within a mini-family)

$$\left.\begin{aligned} R[S_{kp}^j, S_{kp}^{j'}, \tau] &= N & [j = j', \tau = 0] \\ &= N_1 & [j \neq j', |\tau| \leq \Delta] \end{aligned}\right\} \quad \cdots (18)$$

They correspond to the characteristics shown in Fig. 3 (a), (b), and (c), respectively.

Fig. 11 is a block diagram showing the method of constructing a composite set of ZCCZ sequences denoted by $S_{kp}^{j}(k=1,2,\ldots,K,\ p=1,2,\ldots,P\ and\ j=1,2,\ldots,J)$ in an embodiment of the invention. This method is already explained in detail using Eqs.(8) to (18). Here let us explain the production process of a composite set of ZCCZ codes with the drawing. There are three code generators, denoted by ZCZ (Zero Correlation Zone)-Code Gen, H (Hadamard)-Code Gen, and P (Semi-orthogonal)-Code Gen, respectively stated previously. By applying a code length N_1 and a zero correlation zone length 2Δ to ZCZ-Code Gen, it provides a Code C consisting of K of ZCZ sequences in Eq.(8); each is named by the $k-th$ sequence C_k using a well-known technique. By applying a code length N_H to H-Code Gen, it provides a Hadamard matrix H_{00} with a Matrix size of [$N_H \times N_H$] in Eq.(13) using a well-known technique. By applying a code length N_H to P-Code Gen, it provides a Semi-orthogonal code {s_p} with a relatively large Humming distance between a pair of the member sequences in Fig.9, consisting of P of Semi-orthogonal sequences; each is named by the $p-th$ sequence $s_p(p=1,2,\ldots,P)$. A diagonalizing block shown in DIA has a function of producing a supplementary matrix denoted by S_p with a matrix size of [$N_H \times N_H$] by placing the $p-th$ s_p sequence on the diagonal entries, using a well-known technique with Eq. (14).

Said matrices H_{00} and S_p are applied to a modulator MOD1 to produce a matrix demoted by H_P with a matrix size [$N_H \times N_H$]. The first column of matrix H_P is deleted at a deletion block

DEL which outputs a deleted matrix denoted by $H_P^{\bullet}$ with a matrix size $[N_H \times (N_H - 1)]$, consisting J of block sequences denoted by $d_{pj}(j = 1,2,\ldots,j,\ldots,J)$. In this process, the following relation holds good. $J = N_H - 1 = N_2$ where N_2 is a code length of the block codes shown as d_j in Eqs.(9) and (12) or as d_{Pj} in Eq.(15). The $j-th$ block sequence d_j is considered a special case of $d_{Pj}(P=1)$ in Fig.2 (a). At a selection block denoted by SEL, the $j-th$ block sequence $d_{Pj}(N_2)$ with sequence length N_2 out of a set of the $p-th$ block code $H_P^{\bullet}$ is extracted, and then repeated N_1 times at a repeating block $REP(N_1)$ to make an extended block sequence denoted by $d_{Pj}^R(N_1N_2)$.

On the other hand, the $k-th$ ZCZ sequence C_k is applied to a repeating block $REP(N_2)$ to produce an extender block sequence denoted by $C_k^R(N_1N_2)$. Both sequences, C_k^R and d_{Pj}^R are applied to a modulator MOD2 to output a ZCCZ sequence denoted by S_{kp}^j which a product sequence is made of the $k-th$ ZCZ sequence and the $pj-th$ block sequence, where the basic function is shown in Eq.(11) for a case of $P=1$. Therefore, a composite set of ZCCZ sequences, S_{kp}^j is layered by parameters k, p and j.

To assign family elements k, p, and j of a ZCCZ sequence family having such correlation characteristics to the system elements (cell, user, and information level) of a CDMA mobile communication system, the following four examples are considered.

(A) K users/cell (sub-families/user) system.

This is a system of assigning S_{kp}^j to the k-th user (mobile

station). From the number of sequences 2PJ (including polarity inversion) available for each user, the information quantity per frame is

$$I = \log_2 2PJ \qquad \cdots (19)$$

and K users are allowed to transmit $I = \log_2(2PJ)$ bits simultaneously by using the sequence with sequence length N. Since the correlation characteristics stated above can be achieved when using an expanded frame as mentioned previously, using the frame expansion factor α in Eq. (6) and Δ in Eq. (4), the number of chips (equivalent sequence length) required for sending one bit is obtained as follows:

$$\nu_A = \frac{N(1+\alpha)}{K \log_2(2PJ)} = \frac{2\Delta N_2(1+\alpha)}{\log_2(2PJ)} \qquad \cdots (20)$$

(B) KP users/cell (mini-family) system

This is a system of assigning S_{kp}^{j} (j = 1, 2, ..., J) to the [(k-1)P+P]-th user. From the number of available sequences 2J, it leads to

$$I = \log_2 2J \qquad \cdots (21)$$

and hence the number of chips per bit is

$$\nu_B = \frac{N(1+\alpha)}{KP \log_2(2J)} = \frac{2\Delta N_2(1+\alpha)}{P \log_2(2J)} \qquad \cdots (22)$$

(C) (P users/cell) × K cells (sub-families/cell) system

This is a system of assigning one of the sub-families to each cell in order to eliminate the inter-cell interference. In this case, when P users are assigned to each cell, the number

of available sequences for each user is 2J, and hence

$$I = \log_2 2J \qquad \cdots (23)$$

and the number of chips per bit is

$$\nu_C = \frac{N(1+\alpha)}{P\log_2(2J)} \qquad \cdots (24)$$

Therefore, the number of cells that can be assigned is given by,

$$N_C = K = N_1/(2\Delta) \qquad \cdots (25)$$

(D) (J users/cell) × K cells (sub-families/cell) system

Similarly to system (C), this system is capable of eliminating the inter-cell interference, where J users are assigned to each cell, and each user can transmits a multiary modulated frame with 2P level. The same parameters as those given to (C), are derived as follows.

$$I = \log_2 2P \qquad \cdots (26)$$

$$\nu_D = \frac{N(1+\alpha)}{J\log_2(2P)} \qquad \cdots (27)$$

$$N_D = K = N_1/(2\Delta) \qquad \cdots (28)$$

The transmitter of system (C) is designed with a circuit shown in Fig. 2. By changing parameters in accordance with respective systems, the other systems (A), (B) and (D) can be constructed nearly on the same configuration as shown in Fig. 2.

For these four systems, chips/bit are calculated with the parameters of the ZCCZ sequence family stated above, and are compared in Table 1.

Table 1 Example of design parameter of ZCCZ sequence

ZCCZ sequence parameters	$N_1=8$, $\Delta=1$, $K=4$ $N_2=15$, $P=8$, $J=16$ $L=5$ $\alpha=[2\Delta/(N_1+N_2)]=1/60$
Information rate	$I_s=16$kbps

(a) Design parameters of sequence family

	A	B	C	D
N_U	4	32	8	16
N_M	256	32	32	16
I(bits/frame)	8	5	5	4
r_m(km)	4.62	2.90	0.37	0.30
γ	0.3	0.3	2.3	2.3
ν (chips/bit)	3.75	0.750	3.00	1.87

(b) Comparison of chips/bit

For systems (A) and (B), the cell radius is determined, so as to satisfy condition $\Delta = 1$, as shown in the table.

A practical value required for Δ is represented by the following equation, assuming the maximum cell radius r_m and the symbol period T_D associated with the required information rate.

$$\Delta = \left\{\frac{\tau_v}{IT_D}\right\}N \quad \cdots (29)$$

where τ_v is the time variation width in Eq. (5). Assume the speech transmission rate is 16 kbps, and the period is $T_D = 1/(16k)$. For an example case of multiary transmission of $I = 5$, the resultant

symbol period is $T'_D = IT_D = 312.5$ μsec. If the transmission timing of users in a cell by the base station can be controlled almost ideally, Eq. (5) results in $\tau_a \fallingdotseq 0$ may be reduced in Eq. (5). Therefore, for system (A), from the natural environment causing radio wave reflection in the cell, τ_v is given by the following equation.

$$\tau_v \fallingdotseq \tau'_m \fallingdotseq \gamma \tau_0 r_m \quad \cdots (30)$$

where γ is the ratio of delay time τ_v to cell radius propagation time and τ_0 is the unit propagation delay time (sec/m). Assuming $\gamma = 0.3$, from the following equation, the cell radius satisfying $\Delta = 1$ reduces $r_m = 4.6$ km. Similarly for system (B), r_m is obtained and shown in Table 1.

$$r_m = \frac{IT_D}{\gamma \tau_0 N_1 N_2} \quad \cdots (31)$$

Now consider system (C). In this case, the influence of the maximum delay time τ_a caused by the inter-cell interference must be included in γ in Eq. (31). Assuming $\tau_a = 2\tau_0 r_m$, it reduces $\gamma = 2.3$ and $r_m = 0.37$ km. Similarly, r_m is obtained for system (D). These system design values shown in Table 1 are of sufficiently achievable.

For operating CDMA systems, a small chips/bit ratio cannot be achieved, because the orthogonal property between the spreading sequences is not utilized sufficiently. For example, in a system called cdma-ONE, using the spreading sequences with sequence length N = 64, the a long sequence of symbols is transformed into a long sequence of convoluted symbols by aid

of a convolutional code of rate $R = 1/3$, and then transmitted. Hence, the resultant equivalent sequence length increases to $N^* = 192$, and it is shared by about $K = 10$ users. Consequently, the chips/bit ratio is about $\nu_E \fallingdotseq 20$, and any means for anti-inter-cell interference is not included. Table 1 shows far smaller values as compared with this. Because, in particular, systems (C) and (D) in Table 1 are not subjected to interference from the adjacent cells, stable performance is achieved. In systems (A) and (B) in Table 1, a certain operation allowance must be added in order to avoid inter-cell interference, therefore ν is forced to increase to the same degree as compared to those in the table.

In these four systems, the relation between the three elements k, p, and j characterizing the sequence types and system elements (cell, user, information level) is expressed in Table 2. Generally, however, k, p, and j may correspond to other system elements than those in Table 2. For example, k, p, and j may correspond to user, cell and information level, respectively, or to information level, user, and cell. That is, system elements can be assigned to k, p, j in an arbitrary order.

Table 2 Relation between family elements and system elements

Method name \ Family element	k	p	j
(A)	User	Information level	
(B)	User		Information level
(C)	Cell	User	Information level
(D)	Cell	Information level	User

On the other hand, for systems (A) and (B), the cell assignment, one of the system elements (the same code is used by other cells) is omitted, but generally k, p, and j can be assigned in an arbitrary order to the system elements. For example, all of k, p, and j can be assigned to KPJ users, where the information level is binary. Thus, the correspondence between family elements and system elements can be freely selected depending on the system design requirement.

In system (C), family element k is assigned to a system element, cell number. In this case, instead of assigning sequence S_{kp}^j (j = 1, 2, ..., J) to the p-th user belonging to the k-th cell, d_{pj} may be assigned to the users of each cell, and the k-th ZCZ sequence C_k may be assigned to all the users of the k-th cell, so that N_2 times repetitive sequences $[C_k]N_2$ may be used as scramble and descramble codes. That is, the p-th user belonging to the k-th cell produces a transmit-data symbol $b[d_{pj}]N_1$ which is a symbol composed of N_1 times repeated d_{pj} multiplied by a binary transmission data b. Afterwards, it is multiplied by $[C_k]N_2$ as the scramble code and then transmitted. It results in producing the transmit-data symbol $b[d_{pj}]N_1[C_k]N_2 = bS_{kp}^j$ resulting from Eq. (12). On the other hand, the base

station receiver first multiplies the received base band data symbol by $[C_k]N_2$ as the descramble code, and then despreads the resultant output by a desired station sequence $[d_{pj}]N_1$, it is equivalent to despreading by S_{kp}^j. This is only the difference in management, and the same function is realized.

In these systems, the 0 shift cross correlation between mini-families is not 0 but is LN_1. Considering the increase in the simultaneous interference stations, and the number M' of the direct and delayed waves overlapped in time they generate, the following probability

$$N_1 N_2 < M'LN_1 \quad \cdots (32)$$

cannot be ignored. To avoid such interference, an isolated pilot assisted analyzing system explained below may be employed at the same time.

[Isolated pilot response assisted analyzing system]

In system (C), suppose each cell includes P users. Considering up-link transmission in a cell, there is no inter-cell interference from Eqs. (15) to (17), but intra-cell interference (inter-user-interference) exists in the cell. The base station sends pilot transmission timing information to each user via the down-link. Each user transmits the pilot in a state where no data symbol or pilot frames are transmitted from other users. Therefore, the base station receiver separately receives the synchronously received pilot frames (synchronized with the received frame coming from the desired station) corresponding to respective pilot frames transmitted individually by both the

desired station and respective interference stations, and accumulates the correlation output (pilot) response $\Lambda_p(\tau)$ in the memory $\Lambda_p(\tau)$ is a correlation function with sift variable τ which is obtained as the output of a matched filter matched to, for example, the sequence assigned to the desired station 1 when a received frame r_p [or expressed as $r_p(i)$ when noticing the time impulse train] corresponding to a pilot frame transmitted by the p-th user is applied to the matched filter.

Consider using of the ZCCZ sequence family shown in Fig. 6, which corresponds to K = 2, P = 4, J = 1. For example, in the first cell, as the pilot response of assigned sequence S_{1p} (p = 1, 2, 3, 4), the correlation function given by the following equation is provided at the base station.

$$\Lambda_p(\tau) = r_p * S_{11} = \sum_{s=0}^{N-1} \lambda_{sp}\delta(\tau - s) \quad \cdots (33)$$

where * is the symbol for calculating the periodic correlation function. [Here, as a matching object sequence of the matched filter, another sequence, for example, S_{1p} ($p \neq 1$) may be selected.] Further, λ_{sp} is the s (chip) shift correlation value and N is the sequence length (N = 24 from Fig. 6).

As for a data symbol r_D arriving at the other timing than pilot timing, the response is given by

$$\Phi(\tau) = r_D * S_{11} \quad \cdots (34)$$

Ignoring the white noise, since the data symbol response is a sum with respect p of the p-th response which is a product of $\Lambda_p(\tau)$ and the p-th user transmission data b_p, the following

relation is derived.

$$\Phi(\tau) = \sum_{p=1}^{4} b_p \Lambda_p(\tau) \quad \cdots (35)$$

Therefore, representing $\Lambda_p(\tau)$ (τ = 0 to 3) by a matrix $[\Lambda]$, we obtain

$$[\Lambda]\,[\tilde{b}] = [\Phi] \quad \cdots (36)$$

$$\begin{pmatrix} \lambda_{00} & \lambda_{01} & \lambda_{02} & \lambda_{03} \\ \lambda_{10} & \lambda_{11} & \lambda_{12} & \lambda_{13} \\ \lambda_{20} & \lambda_{21} & \lambda_{22} & \lambda_{23} \\ \lambda_{30} & \lambda_{31} & \lambda_{32} & \lambda_{33} \end{pmatrix} \begin{pmatrix} \tilde{b}_1 \\ \tilde{b}_2 \\ \tilde{b}_3 \\ \tilde{b}_4 \end{pmatrix} = \begin{pmatrix} \Phi(0) \\ \Phi(1) \\ \Phi(2) \\ \Phi(3) \end{pmatrix} \quad \cdots (37)$$

where $\sim b_p$ is an analyzed and estimated data transmitted from the p-th user.

In addition, instead of using spreading sequence for the desired station (reference sequence) S_{11} in Eqs. (33) and (34), generally, a spreading sequence with the same sequence length can be utilized. If using an auto-orthogonal sequence instead of S_{11}, there is an advantage such that an error deviation included in the estimated values $\sim b_p$ (an error average from the correct value) due to white noise included in the input data symbol r_D can be estimated from the matrix $[\Lambda]$. An example of auto-orthogonal sequences is a maximum length sequence with added direct-current component.

Referring to the correlation characteristics of this sequence family shown in Fig. 7, the first line of $[\Lambda]$ is $\lambda_{00} = 24$, $\lambda_{0p} = 8$ ($p \neq 0$), but when $\sim b_1$ is obtained as a solution from the above equation, it is not subjected to the disturbance

due to λ_{op} ($p \neq 0$). Further, parameters on the second and third lines, when satisfying the shift range $|\tau| \leq \Delta$ (=2), are 0, resulting in simplifying the matrix. It makes the analysis less susceptible to the white noise. That is, using a set of ZCCZ sequences and isolated pilot analyzing method, the interference component between users can be analyzed and estimated more precisely, and even in the case of $\lambda_{op} \neq 0$ [$\lambda_{op} = LN_1$ in Eq. (17)], a system so as to reduce the error rate can be achieved.

Fig. 12 is a block diagram of the base band circuits of CDMA transmitter-receiver in an embodiment of the invention, and the circuits can perform the isolated pilot assisting function mentioned above. Fig. 12 (a) is a circuit diagram of the transmitter, in which b_{kpn} is the same as the symbol used in Fig. 2(a), and is the n-th binary transmission data. Further, ρ is the pilot information, and, for example, always $\rho = 1$. A pilot insertion circuit PI inserts ρ into the transmission data sequence [b] of b_{kpn} periodically at a certain frequency. A modulator MOD3 determines the polarity of the spreading sequence S_{kp} assigned to this user according to the respective bit information output [b]/ρ PI produces. This output is sent to a frame expansion circuit FE, in which spreading sequence b_{kp} $[S_{kp}(in)]_E$ is produced. Therefore, the transmission signal is represented by the following equation.

$$s(i) = b_{kp}[S_{kp}(i)]_E \qquad \cdots (38)$$

where for the sake of simplicity, the symbol number n is omitted, and b_{kp} is used by assuming J = 1 for $S_{kp}{}^{j}$.

Fig. 12 (b) is a base band receiver circuit, in which $r(n)$ is a received input, A is a gate, and e_D and e_P are timing signals for separating the general data symbols and the isolated pilot frames on the synchronously received symbols. The synchronous reception gate output $r_{kp}^*(n)$ is an input corresponding to the pilot frame transmitted by the p-th user of the k-th cell, and an analyzer P-AYZ analyzes it, and produces the correlation function output $\Lambda_{kp}(\tau)$. Here, because that intra-cell interference between users exists, but there is no inter-cell interference (k may be a constant), P pieces of $\Lambda_{kp}(\tau)$ are obtained. They are accumulated in a memory MEM in a form of matrix Λ in Eqs. (36) and (37).

On the other hand, the synchronous reception core-output $r_D^*(in)$ is a data symbol bearing transmission data b_{kpn}. An analyzer D-AYZ analyzes $r_D^*(n)$ based on Eq. (37), using the matrix stored in MEM. The output $\sim b_{kpn}$ is applied to the hard decision circuit DEC which outputs the detection output $\hat{}b_{kpn}$. In this circuit, the interference between users is eliminated, and received code error rate is reduced.

As explained in detail above, the invention presents means for generating a composite set of ZCCZ sequences which have a stratified structure capable of flexibly adapting with design requirements on system elements, and have a zero correlation zone in the cross correlation characteristics, on the basis of a ZCZ sequence set having zero correlation zone in its correlation characteristics and a block code set with a large Hamming distance, and further presents means for avoiding interference disturbance

caused by symbols transmitted from other users in the cell or from users belonging to other cells, and further interference disturbance caused by multiple delayed waves generated by transmitted waves addressed to a desired station, by assigning ZCCZ sequences to each user as the spreading sequences for transmission within a cell in a mobile communication system, or assigning to the users in respective cells as the spreading sequences for multi-cell transmission for plural cells, and employing an expanded frame structure and assuring quasi-synchronous conditions. By employing such means together with the isolated pilot response assisted analysing system, the invention further presents means for avoiding cross correlation between sequences of the sequence family. Therefore, when the invention is applied to a mobile communications system or wireless LAN, owing to its interference avoiding characteristics, it is possible to construct a system which achieves a low error rate and high frequency utilization efficiency, bringing about outstanding effects.